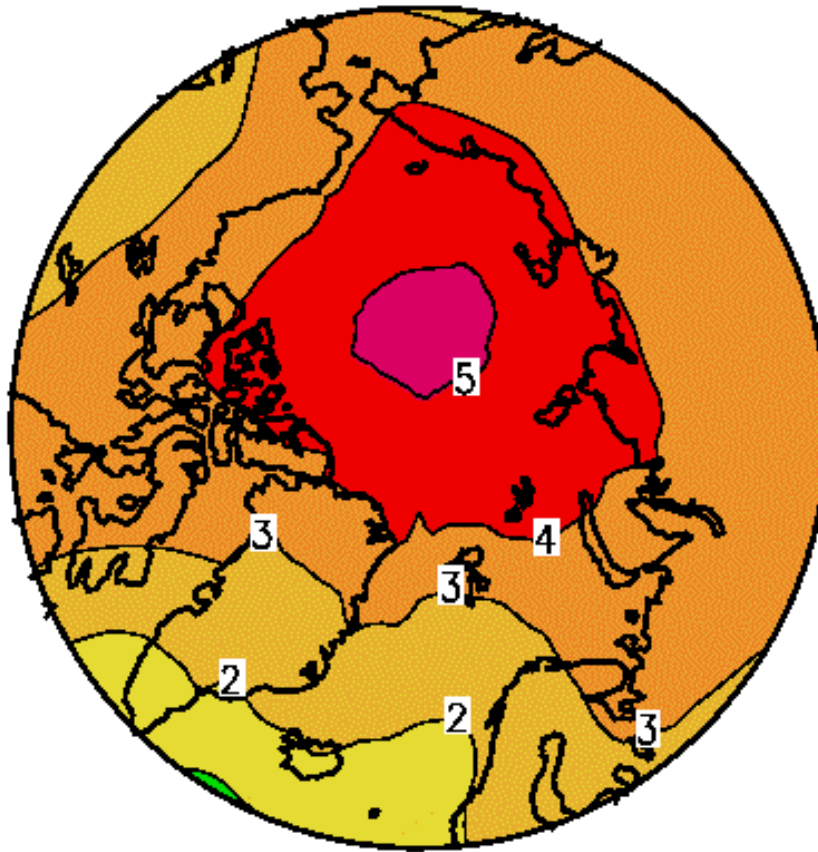# Report from the Arctic Climate Impact Assessment Modeling and Scenarios Workshop

Stockholm, Sweden   January 29-31, 2001

Chairs: Erland Källén, Vladimir Kattsov, John Walsh and Elizabeth Weatherhead

The figure shows simulated annual mean temperature changes for the year 2070 over the region north of 60° latitude. The results were averaged from 19 climate models. These models were used to predict future climate based on a simple increase in greenhouse gas levels, rather than on any of the more advanced scenarios developed for climate assessments. The results clearly show that temperature changes are expected to be greater in the Arctic than at lower latitudes. The changes expected for the Arctic are not zonally symmetric, and the predicted magnitudes and geographical patterns of change differ substantially from model to model. Individual model results tend to show greater regional changes than are illustrated here. Courtesy of Jouni Räisänen.

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Report from the

Arctic Climate Impact Assessment Modeling and Scenarios Workshop

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Chairs: Erland Källén (Univ. of Stockholm, Sweden), Vladimir Kattsov (Voeikov Main Geophys. Obs., St Petersburg, Russia), John Walsh (Univ. of Illinois, Champaign/Urbana, USA) and Elizabeth Weatherhead (Univ. of Colorado, Boulder, USA).

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Electronic versions of the figures used in this document are available at http://www.srrb.noaa.gov/UV/arctic.html and by anonymous ftp to ftp.srrb.noaa.gov/pub/arctic.

Executive Summary:

The Modeling and Scenarios Workshop meeting was held to help set the foundation for the Arctic Climate Impact Assessment (ACIA). The group was charged with the task of making specific recommendations regarding the models and scenarios to be used in the ACIA, particularly for chapters dealing with terrestrial, marine, infrastructure and other impacts. The meeting lasted two and a half days and included invited presentations as well as break-out discussions for developing recommendations. The final plenary session allowed for presentations by the break-out groups and resulted in the following conclusions.

The Arctic is recognized as the area of the world where climate change is likely to be largest, and is also an area where natural variability has always been large. Current climate models predict a greater warming for the Arctic than for the rest of the globe. The impacts of this warming, including the melting of sea ice and changes to terrestrial systems, are likely to be significant. The projections of future changes are complicated by possible interactions involving stratospheric temperature, stratospheric ozone, and changes in other parts of the Arctic system. For this reason, current estimates of future changes to the Arctic vary significantly. The model results disagree as to both the magnitude of changes and the regional aspects of these changes. The large range of future predictions requires special consideration and synthesis in order for the impacts assessment work of ACIA to proceed in a coordinated manner.

It is proposed that a central ACIA resource be established to provide an interface between the climate model scenario data and the individual impact scientists. It was the opinion of the workshop participants that unless such a facility is established, the ACIA process is likely to fail.

Climate models
Atmosphere-Ocean General Circulation Models (AOGCMs), regional climate models (RCMs), and statistical downscaling methods all have value for estimating future climate change impacts to the Arctic. Current AOGCMs differ significantly with respect to both the magnitude and distribution of future changes, as demonstrated by the Coupled Model Intercomparison Project 2 (CMIP/2) results, and by the information collected by the Intergovernmental Panel on Climate Change (IPCC) Data Distribution Centre (DDC). However, these models can still guide our understanding of what may happen in the Arctic in the coming decades. On average, the models indicate a 2 to 6 degrees C warming of the Arctic by the year 2070, with considerable uncertainty around these estimates and large model-to-model differences. Although many emission assumptions exist for the future, the range of projected Arctic temperature responses is similar to the range of responses observed due to model-to-model differences.

Scenarios
Two types of scenarios exist for assessing climate impacts: scenarios for future emissions of greenhouse gasesand aerosols; and scenarios of the future physical environment. In agreement with IPCC's approach, appropriate emission scenarios will be assumed and AOGCMs will be used to project the resultant changes to the physical environment.

No new emission scenarios need to be developed for ACIA. The scenarios developed by CMIP/2 (a 1% per year increase of CO_2) and IPCC (IS92 and SRES) are useful for assessing model-to-model differences. To stay coordinated with the current IPCC efforts, the group has agreed to work from IPCC SRES scenario B2, which offers what may be considered a likely scenario for the future. Results will be analyzed and summarized for the scenarios chapter of the ACIA assessment.

A growing number of groups have been working on AOGCMs and are producing IPCC B2 scenario runs. While it is recognized that some models may be more appropriate for Arctic use, it is currently difficult to establish criteria determining which AOGCMs should or should not be used. As a starting point, it is proposed that ACIA follow the selection of models made by IPCC in their climate scenario database. Currently, model results from seven different modeling groups are available in the IPCC database.

Ozone and UV modeling
With respect to modeling ozone and UV levels, the World Meteorological Organization (WMO) has taken a lead. Their next assessment is due to be completed in 2002. They have not yet defined the scenarios to be used in that assessment, but coordination needs to be established between the activities of ACIA and the activities of WMO. Current 3-D models able to include the impacts of climate change indicate that the Arctic may experience continued depletion of ozone for the next twenty years. This depletion will likely be followed by a slow recovery period.

Time Slices
The time slices for special consideration will be centered around 2020, 2050 and 2080. These time scales are also being given special attention by IPCC. Results from models will have to be examined for some number of years around these times to represent average values as well as the characteristic variability. Characterizing the changes in extreme events will require using historical data and daily model output in addition to the monthly output typically archived. A record length of ten to thirty years will be examined for each time slice.

Regional Models
Regional models will be needed to address all the spatial and temporal scales of relevance to Arctic impacts. The finer spatial and temporal scales will be particularly important for assessing extreme events as well as very local impacts. A number of regional models exist for specific areas of the Arctic, but there is currently no working coupled ocean-ice-atmosphere regional model for the Arctic as a whole. This lack was recognized as a serious gap in our current ability to assess climate change impacts in the

Arctic. A number of groups would like to work on developing an appropriate model and may get support in the future.

Statistical Downscaling

For some small regions of the Arctic, a considerably finer grid-scale (e.g. 50 m. by 50 m.) will be needed to assess terrestrial impacts, such as impacts to vegetation and infrastructure. This scale can only be achieved by statistical downscaling from global or preferably regional models. Areas of long-term ecological monitoring, as near Abisko, Toolik Lake and Svalbard, would benefit from such efforts.

Understanding Uncertainties

Uncertainties for climate change predictions are recognized to be large. These uncertainties stem from our assumptions about the future, from the models themselves and from inherent limitations in our ability to predict climate. There is currently considerable uncertainty in predictions for the Arctic at a number of levels: different scenarios, different models and different runs from a single model. Unfortunately, agreement within runs of one model or between different models does not necessarily imply a high degree of certainty in the results. Tools need to be developed to synthesize the results and their associated uncertainties for the impacts communities. The scenarios working group will address these issues using a number of different methods.

Parameters for Impacts use

A large number of parameters on a range of spatial and time scales will be useful in addressing the range of impacts studies being considered. In addition, both the mean values as well as knowledge of the frequency of extreme events are of use to the impacts communities. A table has been developed to attempt to outline the range of parameters and scales of use. It is recognized that obtaining and using all of these parameters for the full spatial and time scales requested will be intractable. It is likely that a subset of this list of parameters will need to be developed. The subset should be defined by the impacts communities. Some parameters, such as cloud cover or other data, will need to be requested directly from the modeling groups. A small subset of parameters will be gathered from the various modeling groups and these data will be made available for impacts studies.

Linkages to Impacts Communities

In general, there is an immediate need to develop linkages between the modeling communities and the impacts communities. The needs of the impacts communities require more attention to ensure that the authors of ACIA impact sections get the data and appropriate information they need in an efficient manner. To make ACIA successful, a resource of this type is needed for dedicated use. It is proposed that a central resource be established to provide an interface between the climate model scenario data and the individual impact scientists. More detailed specifications for such a resource need to be worked out, but two persons working full time will likely be required.

Regional Climate Impact Studies in the Arctic
Manfred A. Lange

The need to consider global climate change, its possible impacts and appropriate mitigation and/or adaptation measures is undisputed among scientists, decision makers and the public at large. It is equally accepted that in order to deal with these problems integrated impact studies provide a useful, if not the only feasible tool. However, only more recently has it been realised and acknowledged (e.g., by the *Intergovernmental Panel on Climate Change)* that the regional and even sub-regional manifestation of climate change requires impact studies that are designed to addresses these scales. Thus, global impact assessments are being complemented by ***integrated regional impact studies*** (IRISs) that are now pursued in various places around the globe.

Completed and ongoing studies

In the Arctic, IRISs have a relatively long history. The first one ever (at least to my knowledge) goes back to a national initiative. The *Mackenzie Basin Impact Study* (MBIS) was started in the early nineties as an integrated impact study for the Mackenzie Basin in north-west Canada (Figure 1). MBIS was conducted over a six-year period and came to a conclusion in 1997 (*Cohen*, 1994; *Cohen*, 1997a; *Cohen*, 1999). The results obtained indicate that climate warming may lead to more frequent landslides due to permafrost thawing, lower minimum annual river and lake levels, more forest fires and lower yields from softwoods in the Mackenzie Basin. These impacts could possibly offset the more positive consequences of climate change such as a longer growing season, increased forest productivity and a longer ice-free season.

A particular emphasis was placed on the information of and the interaction with local and regional stakeholders (*Cohen*, 1997b). Throughout the study, a large number of stakeholders including representatives of provincial and territorial governments, aboriginal organisations and the private sector were contacted and a joint scientist-stakeholder steering committee was
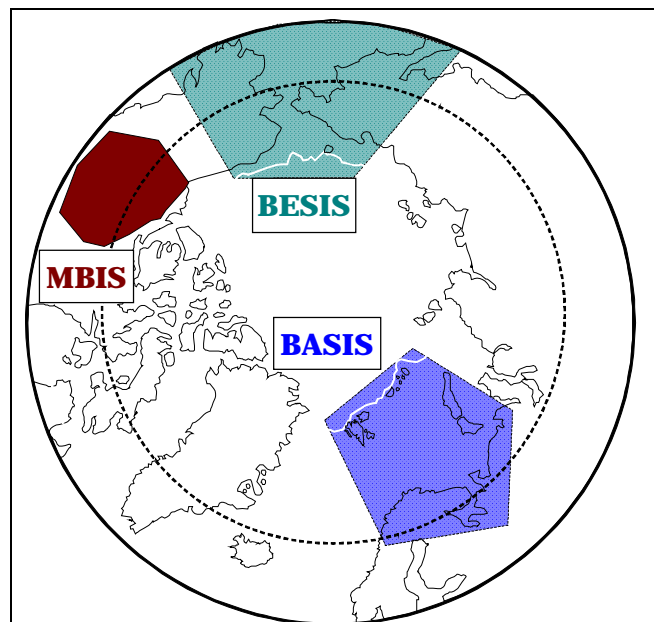

Figure 1: *Simplified representation of study regions for IRISs in the Arctic*

formed, thus enabling a fairly extensive scientist-stakeholder collaboration. MBIS, despite its finite duration and scope, resulted in a wealth of important results, which provide valuable guidance to other regional integrated impact studies in the Arctic. The *International Arctic Science Committee* (IASC) recognised early on that global changes and their impacts represent topics of particular importance to the Arctic and its inhabitants. In 1991, at the first meeting of its Council, it established as its first working group the IASC *Working Group on Global Change*. In 1992, at a meeting of the working group and a large number of additional participants IASC produced an international framework and broad plan for a regional research program looking at the role of the Arctic in global change (*International Arctic Science Committee (IASC)*, 1994). The IASC *Working Group on Global Change* in its meeting of October, 1994 formulated as one of its research priorities to address the impacts of Global Changes on the Arctic. Based on a set of criteria, two regions were selected for future investigations, the Barents Sea and the Bering Sea region (Figure 1). This was the start of what is now known as the *Barents Sea Impact Study* (BASIS) and *Bering Sea Impact Study* (BESIS) (*Kuhry*, 1994). Both studies have been IASC priority projects and provide various useful results that can and should be utilised in ACIA (cf., *Weller and Lange*, 1999) BASIS and BESIS, although considered 'sister projects' with a fairly comprehensive approach and a quite extensive agenda have been conducted differently. While BESIS largely relies on integration and experts' judgement workshops (including the involvement of relevant stakeholders) (see, e.g., *Weller and Anderson*, 1998), BASIS has been carried out largely as a dedicated EU-funded research project (cf., *Lange*, 1997a; *Lange*, 1997b; *Lange et al.*, 1999a) that explicitly included a sub-project dealing with stakeholder concerns and their active involvement (*Lange et al.*, 1999b).

Lessons to be learned

- While all of the three projects described above have provided valuable insights into the possible consequences of climate change in their respective study region, it is clear that there is still significant need for additional investigations. However, when pursuing this need, the following points should be kept in mind:
- Because of the large diversity of natural, socio-economic and political conditions in the circumpolar North, a sub-regional approach to climate impact assessments (i.e., an approach that subdivides the Arctic in a number of regions that each have common characteristics) represents an appropriate strategy.
- However, when following such an approach, care should be taken to ensure integration of the results of each study into a circumpolar framework. This has not sufficiently been done in the case of the aforementioned studies.
- This involves harmonisation of basic methodologies including the selection of comparable base case scenarios for physical/environmental processes as well as socio-economic developments and the specification of common (regional) climate scenarios.
- Care should also be taken to ensure the proper involvement of local as well as regional stakeholders, the latter including indigenous organisations such as the *Saami Council* or the *Inuit Circumpolar Conference*.

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Possible climate impacts on marine ecosystems
Harald Loeng

Abstract

The thermohaline circulation dominated by the Arctic Ocean and Nordic Seas is responsible for as much as half of the Earth's poleward heat transport. Alterations of this circulation, as have been observed during climatic changes of the past, can affect global climate and in particular the climate of Europe and North America. The latest main changes seem to be these: that in the late 1980s-early 1990s, a warmer, fresher and probably stronger transport of Norwegian Atlantic Water was carried north to the Fram Strait and Barents Sea. Entering the Arctic, the Atlantic derived sublayer shoaled and warmed up to 2°C in the Eurasien Basin and extended in distribution by about 20%. There are clear indications of covariance of variety of aspects of the North Atlantic Ocean and the overlying atmosphere and, perhaps crucially, suggestions of a participation of oceanic advection in that covariance in such a fashion as to have a potential for oceanic feedback to the atmosphere.

Regime shifts in the ocean will have impact on distribution of commercial important fish stocks. There are several examples on such impact, especially on species living in their marginal area where very small changes may have large influence on these stocks. One example is the northward migration of cod along the west coast of Greenland during the warming from the 1920s up to the late 1930s. The warm period came to an end in the late 1960s and the subsequent period consisted of three extremely cold periods attributed to different geophysical events. The West Greenland cod stock has not produced any good year classes since the cooling. An other example is the Norwegian Spring Spawning Herring. During the warm period that lasted from 1920s up to mid 1960s, this herring stock had its feeding migration to Iceland. However, a marked climate shift with a decrease of about 1°C had that the consequence that the herring gradually disappeared from Iceland. In the Barents Sea, rich year-classes of cod occur only in years with relatively high temperature on the spawning ground and their areas of their distribution during the first half-year of their lives. Feeding distribution of cod, haddock and capelin depend on the climatic conditions with more easterly and northerly distributions noted in warm years than in cold ones. The growth of fish also seems to depend on the environmental temperature, but the temperature growth relationship is probably not simple. The climatic fluctuations also influence the plankton production and thereby the food conditions for all plankton feeders. Temperature effects linked to the variability of food may therefore be as important as the direct effect of temperature on the biological conditions of fish.

The ACIA Drafting Group on Marine Systems discussed possible climate impacts on marine ecosystems during their first meeting in Copenhagen in January 2001. They also came up with a list of requests for the scenario group and concluded that modelers will unlikely be able to provide the marine drafting group with all parameters and variables wanted. However, it was agreed to take the scenarios they provide and develop impact responses to these. If the marine group feels that these scenarios are not correct or have not gone far enough they will develop additional scenarios that we feel are more representative and provide responses to these as well. Discussions were held on whether modelers in addition to those involved in ACIA report should be requested to help the marine drafting group in the development of these scenarios

It is paramount that the scenarios be provided to the marine group at the earliest possible date in order to proceed with developing the impacts to these potential changes.

Impact on Arctic Infrastructure
Dr.ing. Arne Instanes
Associate Professor University Courses on Svalbard (UNIS)

There are increased concerns related to the impact of a possible global climatic change on Arctic infrastructure. Especially important is how the climatic scenarios may change (increase) the environmental loads the structures are designed for and cause increased risk of damage to infrastructure and threat to human lives. In addition, future design of infrastructure in the Arctic may be directly affected by climate change.

Engineering design for Arctic infrastructure does in general include:

i)   Probability analysis of the loads the structure will be subjected to during its lifetime.

ii)   Evaluations of how these loads affect the structure at different levels of risk.

Environmental loads are typically ocean waves and currents, wind, precipitation, ice conditions and permafrost temperatures. The magnitude of an environmental load is dependent on the probability of occurrence.

In order to evaluate the impact of climatic change on Arctic infrastructure, the author is of the opinion that climate change has to be treated in a similar manner to environmental loads. This means that the climatic scenarios must have a probability of occurrence or "likelihood" connected to the prediction.

In this presentation the existing engineering design procedures for Arctic infrastructure are briefly presented, and the climatic scenario input data needed for infrastructure impact studies discussed.

UV Impact Studies
E. C. Weatherhead

Ultraviolet (UV) radiation from the sun has long been a stressor in the Arctic. Although UV radiation amounts to a horizontal surface are considerably less in the Arctic than at lower latitudes, UV to a vertical surface, such as the human face or trees, is considerably higher than at mid-latitudes. The difference is particularly apparent during the spring when highly reflective snow is present. Photokeratitis, commonly known as snow-blindness, occurs often in the Arctic, and is a direct effect of UV radiation. The Arctic is the only place on earth where native peoples are known to have developed methods to protect themselves from this problem.

UV to a vertical surface is generally higher in springtime than at any other time of year, depending on snow cover. These high values coincide with the time of maximum ozone depletion as documented by both surface and satellite measurements. They also coincide with the time of year when many biological systems have not yet developed natural protection against UV. Fish eggs, leaf buds and even human skin are generally most sensitive to UV in the springtime. This combination of naturally high UV levels with maximum ozone depletion and sensitive biological systems makes spring a critical time for many Arctic organisms susceptible to UV.

Ultraviolet radiation has a large range of impacts in the Arctic. Both species-specific impacts and ecosystem-wide impacts have been observed and are often non-linear in their effects. UV affects fish egg mortality as well as phytoplankton motility and survival rates in marine systems. UV affects plant growth and the digestibility of plants by both insects and animals in terrestrial systems. In humans, UV is associated with three categories of effects: dermatological, including skin cancer and sunburn; ocular, including cataracts and snow-blindness; and immune suppression, which can affect the severity and frequency of diseases.

Some of the impacts of UV, such as cataract formation, are the result of cumulative exposure over periods of weeks to years. Other impacts, such as fish egg mortality or sunburn, are results of exposure over periods of hours. Thus, we must understand both extreme UV events as well as long-term trends in UV in order to accurately assess UV impacts in the Arctic.

Estimates for future UV levels depend on predictions of changes in cloudiness, ozone, surface albedo and aerosols. Future UV levels will therefore be directly affected by both ozone depletion and climate change. Current estimates indicate that ozone levels will continue to decline in the Arctic for the next fifteen to twenty years, and then will begin a very gradual recovery. The impacts of these perturbed UV levels in the Arctic

are not well known at this time and there are few groups currently working on these issues.

Climate change of the Arctic region as forced by global anthropogenic effects.

Lennart Bengtsson

Observational data suggest that the climate in the Arctic region undergoes considerable variations on a decadal time scale and longer. The rapid warming in the 1930 at least in the Atlantic sector followed by a slow cooling over several decades is very intriguing. Climate change modeling studies show a very strong response in the Arctic region in spite of the fact that climate forcing from greenhouse gases has a minimum at high latitudes of the Northern Hemisphere.

A part of the explanation is related to variations of the North Atlantic Oscillation (NAO) or Arctic Oscillation (AO) which undergoes semi-chaotic variations with considerable amplitudes on longer time scales combined with strong regional ocean and land surface feedback processes. To what extent the AO is chaotic and to what extent it is driven by large scale SST anomalies presumably from low latitudes is still an open question but appears to be taking place.

Climate change experiments carried out at MPI for Meteorology in Hamburg suggest that the warming which have taken place in recent decades could be a consequence of anthropogenic effects. The experiments suggest a further warming and sea-ice reduction in the coming decades. However, climate simulation of the Arctic have still deficiencies, such as limitation to reproduce the very large interdecadal climate fluctuations, and results of the simulations must be judged critically.

Intercomparison of 19 global climate change simulations from an Arctic perspective
Jouni Räisänen

The second phase of the Coupled Model Intercomparison Project (CMIP2) is an intercomparison of standard, idealized climate change experiments with coupled atmosphere-ocean general circulation models (see Meehl et al. 2000 or http://www-pcmdi.llnl.gov/cmip/). Each experiment consists of an 80-year control run with constant "present-day" CO_2 and of a 80-year greenhouse run with gradually increasing (1% per year compounded) CO_2. Here, some results from these experiments are presented from an Arctic perspective.

The doubling of CO_2 in the CMIP2 experiments takes place in 70 years. At this time, the global mean warming in the 19 experiments varies from 1.1 to 3.1ºC, with a mean value of 1.75ºC. This rate of warming is, incidentally, very similar to the warming projected by the IPCC for the B2 emission scenario. The latter amounts to about 2.5ºC between 2000 and 2100, as averaged over the 7 models used by IPCC. This may seem surprising, given that the increase in CO_2 in the B2 scenario is much below 1% per year. However, the warming in the B2 scenario is enhanced by projected increases in other greenhouse gases and reduced sulphur emissions.

In this analysis, 19 models are used: BMRC - Australia; CCC - Canada; CCSR - Japan; CCSR2 - Japan; CERFACS - France; CSIRO - Australia; ECHAM3 - Germany; ECHAM4 - Germany; GFDL-R15 - USA; GFDL-R30 - USA; GISS - USA; IAP - China; LMD/IPSL - France; MRI - Japan; MRI2 - Japan; NCAR-CSM - USA; NCAR-PCM - USA; HadCM2 - United Kingdom; HadCM3 - United Kingdom. It should be noted that models continue to evolve and improve, which means that current model versions from the same centres may in some cases be offering different results for the Arctic. Also, it may be hazardous to conclude that a given model is wrong just because it is an outlier in its simulation of climate changes.
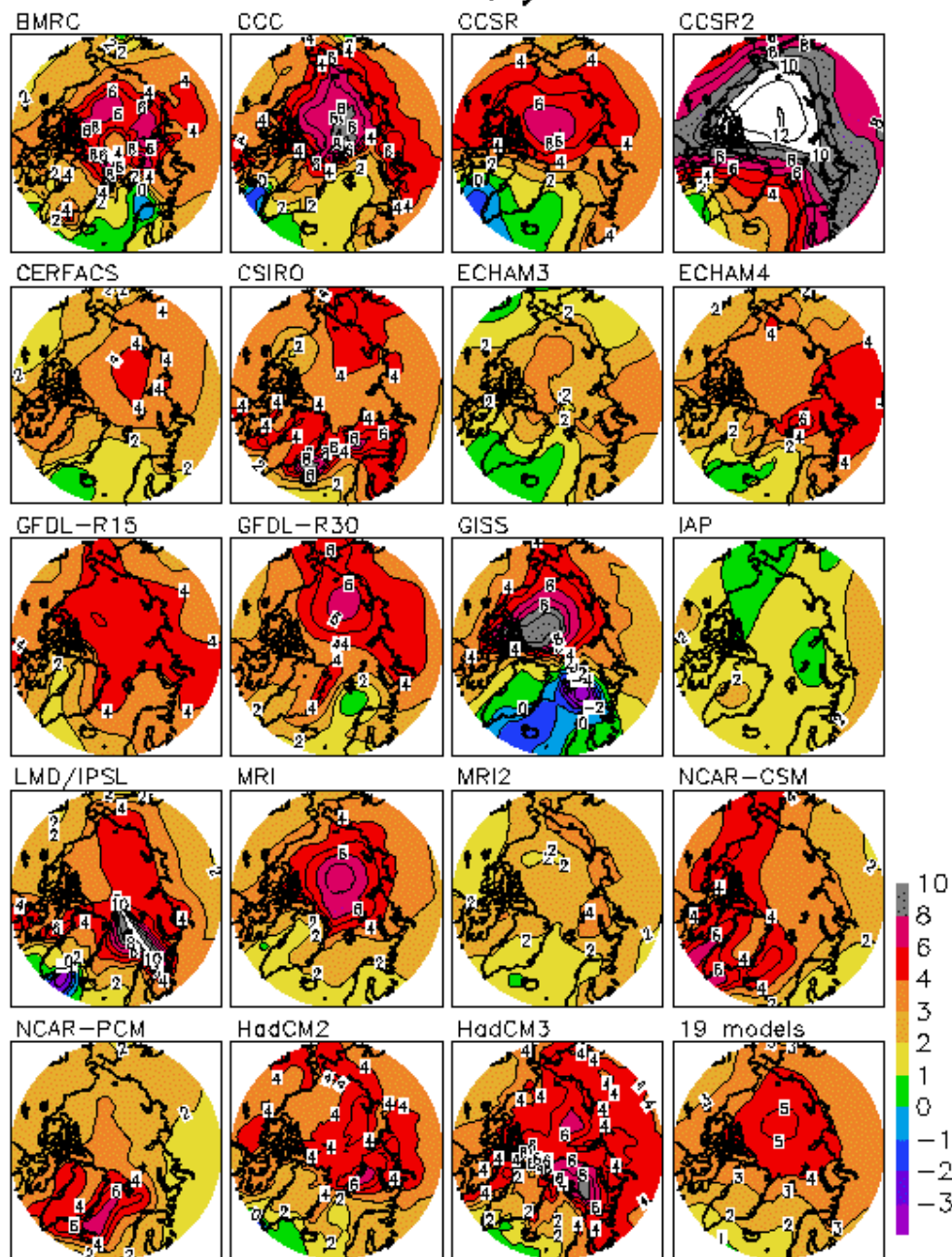
Annual temperature
With a doubling of CO_2, the models generally show a larger increase in annual mean temperature over the Arctic than anywhere else in the world. On the average, the warming amounts to 3.4ºC (double the global mean) for the whole area north of 60ºN, with even larger warming over the high Arctic (Fig. 1). The scatter between the individual models is substantial, however, in the 60º-90ºN area mean from 1.5ºC to 7.6ºC (although 17 of the 19 models are within 2.2-3.9ºC). The model-to-model differences at the sub-Arctic level are even larger, with some models predicting the greatest warming over the Russian part of the Arctic and others over the high Arctic or over the Canadian part of the Arctic. In a few cases, patches of local cooling actually occur over the Atlantic sector. Despite this, the standard deviation between the 19 experiments is typically only about a half of the 19-model mean warming. Thus, although the absolute scatter is large, the relative agreement may still be regarded as reasonably good.

Seasonal temperature

The models generally predict a strong seasonal cycle in the changes in temperature, with the greatest changes in autumn and winter and the smallest change in summer. In the high Arctic, the 19-model mean warming reaches 7-8ºC in autumn and winter but only 1ºC in summer.

ANNUAL MEAN WARMING, years 61-80

Changes in annual mean temperature from 19 CMIP2 experiments, as averaged over the 20-year period centered at doubling of CO_2.

Precipitation
The 19 models simulate, on the average, an about 20% increase in annual precipitation over the high Arctic and about a 11% increase for the whole area 60º-90ºN. Largest increases are projected for autumn and winter and smallest for summer. However, even more so than with temperature, the scatter between the individual experiments is large. The sub-regional patterns of change are noisy and vary strongly between the 19 experiments, from local decreases to increases exceeding 50% in some cases. The local model-to-model standard deviation is generally of similar magnitude with the 19-model mean precipitation increase. Estimating changes in land surface wetness or moisture availability will require considering changes in evapotranspiration as well as precipitation.

Sea Level Pressure
The models generally do not suggest very large CO_2-induced changes in sea level pressure. On the average there is a weak AO-like change (decrease in SLP over the Arctic), but nothing that resembles the strong observed trends over the last 30-40 years. The relative scatter between the 19 simulations is at least as pronounced as with precipitation.

The model-to-model differences in climate change result partly from differences in model characteristics, partly from natural variability ("noise") in the simulations. Using the method detailed in Räisänen (2001), the latter factor is only likely to explain 10-20% of the differences in seasonal and annual temperature changes, but it explains a more substantial part of the differences in the changes of precipitation and, in particular, sea level pressure.

Differences between different models offer important information for interpreting the model results. Disagreement between different models indicates that at least some of the models are wrong. On the other hand, although it is tempting to think so, agreement is not a rigorous proof of that the models would be right. Furthermore, uncertainty about future climate forcing is not an issue in comparing the CMIP2 experiments with the same prescribed increase in CO_2, but it is an issue in complex reality.

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Discussion Summary:

The Arctic is recognized as the area of the world where climate change is likely to be largest, and is also an area where natural variability has always been large. Current climate models predict a greater warming for the Arctic than for the rest of the globe. The impacts of this warming, including the melting of sea ice and changes to terrestrial systems, are likely to be significant. However, current estimates for future changes to the Arctic vary significantly. The model results disagree as to both the magnitude of changes and the regional aspects of these changes. The large range of future predictions requires special consideration and synthesis in order for the impacts assessment work of ACIA to proceed in a coordinated manner.

This group is charged with determining which models and scenarios to use, and with developing appropriate datasets for use by the impacts' communities. In working toward these goals, we recognize that the work done by ACIA will be coordinated with WMO and IPCC to assure that the results are intercomparable and are complementary to ongoing efforts. The workshop achieved major advances in both of these areas. The results of the discussions are summarized below.

Coupled Global Climate Models

Coupled Global Climate Models, or Atmosphere-Ocean General Circulation Models (AOGCMs), are one of our most powerful tools for predicting future climate. These models have demonstrated that the Arctic is strongly sensitive to anthropogenically driven climate change and that the Arctic climate both affects global climate and is affected by global changes. The current global climate models have a coarse spatial and temporal resolution and cannot provide many of the climate elements needed for impact studies. The combined use of AOGCMs and regional climate models (RCMs) and/or statistical downscaling is likely to be a powerful resource for assessing Arctic climate impacts.

Scenarios

Scenarios for future climate change have been identified in the past by IPCC and have been widely used by the climate modeling communities. No new scenarios need to be developed for ACIA. Instead, ACIA will use recent IPCC scenarios based on the Special Report on Emission Scenarios (SRES). Within SRES, IPCC defined forty scenarios. Of these, two have emerged as having particular significance. Although not referred to by IPCC in this manner, the general scientific community has come to identify the A2 scenario as the "Business as Usual" or "Worst Case" scenario and the B2 as the "Best Guess" or "Most Likely" scenario.

A summary of the A2 and B2 scenarios from IPCC Third Assessment Report (TAR) is as follows:

The A2 storyline and scenario family describes a very heterogeneous world. Underlying these is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita growth and technological change more fragmented and slower than other storylines.

The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

The conclusion of this workshop is that the B2 scenario will be the single most useful scenario for the impacts groups to work with. This "Most Likely" scenario is preferred over the A2 or the "Business as Usual" scenario for a number of reasons. First, because the modeled response of the Arctic is so large, it is better to communicate the most likely future situation and avoid criticism for taking an alarmist point of view. Second, multiple runs of the B2 scenario are available from a number of modeling groups, allowing intra-model uncertainties to be assessed. Third, the model transient climate responses for both scenarios seem to be similar out as far as 2050 and only diverge significantly after that time. For comparative purposes, the scenarios chapter of ACIA will include an analysis of both scenarios.

Many of the leading modeling centers have produced one or two runs of A2 and at least two runs of the B2 scenario. A minimum set of output parameters, including monthly averaged surface temperatures, is currently available from the IPCC data center for these runs. Multiple runs from an individual model/scenario are useful for assessing a minimum uncertainty for that set of predictions. Uncertainty is greater when also considering model-to-model differences. This uncertainty is compounded by the inherent limitations in our ability to predict climate as well as the inherent limitations in predicting drivers of climate, such as population growth and energy use in the coming decades.

GCM Groups

A number of different models and modeling groups are currently producing predictions of future climate. None of these models is recognized as being significantly better than all others. Some models, however, are recognized to be more reliable than others. It is extremely difficult to divide the set of available models into those which should and those which should not be used for ACIA. As a minimum set, the seven models

currently available from the IPCC database are likely to be useful. The seven models are as follows: CSIRO-Mk2 (CSIRO, Australia), HADCM3 (Hadley Center, U.K.), GFDL-R15-a (GFDL, U.S.A.), ECHAM4/OPYC3 DKRZ, Germany), NCAR DOE-PCM (NCAR, U.S.A.), CCSR/NIES (Japan), and CGCM1 (Canada).

The 19 AOGCMs participating in the Coupled Model Intercomparison Project 2 (CMIP/2) and 7 AOGCMs archived at the IPCC Data Distribution Centre (DDC) show significant model-to-model differences for both the magnitude of temperature and precipitation changes predicted for the Arctic and for the distribution of these changes. The results underscore the importance of assessing appropriate uncertainty limits for any predictions of future climate change and corresponding impacts. The results may also indicate that some of the models predict conditions in the Arctic better than other models, although the criteria for making such a distinction still need to be developed. Because the availability of these criteria will significantly enhance the assessment enterprise, ACIA should make every possible effort to facilitate their development.

The final criteria for choosing which models are most appropriate for ACIA use will be developed based on future analysis. A minimum criterion will be the existence of appropriate documentation, as well as participation in modeling intercomparisons. Because the Arctic poses specific modeling challenges, it is possible that models performing well at lower latitudes may not be most appropriate for Arctic work.

Ozone and UV Modeling

The ozone losses observed over the past two decades in the Arctic are second in magnitude only to the losses observed in Antarctica. These losses are associated with UV increases that have also been observed and documented. Three complementary sets of predictions were presented at this workshop to demonstrate the range of our current understanding of Arctic ozone and UV changes. The predictions from 3-d models that include climate change indicate that Arctic ozone is likely to decrease for the next twenty years and that this time period will be followed by a slow recovery. Other studies of past mid-latitude ozone changes link dynamics to much of the ozone depletion observed. These studies imply that the future of ozone, and therefore UV levels, in the Arctic is extremely uncertain. WMO is currently preparing its next ozone assessment for completion in 2002. This assessment will likely include new predictions for Arctic ozone and UV, although past emphasis has been on Antarctic and mid-latitude ozone depletion. ACIA should make an effort to coordinate with WMO on their upcoming assessment to assure that the Arctic issues are given appropriate attention.

Time Slices

Specific time slices are useful to define the physical environment and possible ecosystem impacts in the future. Three specific time slices have been agreed on for the ACIA assessment and are centered on the years 2020, 2050, and 2080. These times

were chosen to give representative near-term, mid-term and longer-term outlooks for future changes, as well as to provide consistency with IPCC. A few select model parameters will be gathered for these time scales and some number of years of data will be acquired around each of the time slices to determine both averages and characteristic variability. Within each time slice, the number of years that needs to be gathered depends on the individual parameter being considered and on specific requirements for impact studies. For example, statistical downscaling will require daily model output for periods of about a decade centered on each of the three years.

Ozone predictions for 2020 will be updated in the next ozone assessment and will provide information for the first time slice. In the past, ozone predictions have been carried out through 2055, although the models disagreed considerably by that time. Biologically relevant UV levels can be predicted for these time scales based on the predictions for ozone.

Regional Models

Regional models serve an important role in assessing climate change impacts in the Arctic. Regional models can offer higher spatial resolution of potential future impacts than is currently offered by AOGCMs. The regional models are generally driven by global models, but can be developed with supplemental dynamic feedback mechanisms. Choosing which global model and scenario to use with a regional model is critical for climate assessment applications. Regional models have been developed and are able to provide results for a number of Arctic sub-regions including Sweden, Norway, and parts of Alaska and Canada. This list of sub-regional Arctic models is not yet complete nor is the information currently available on how to contact these groups and obtain results. Systematic intercomparison of about ten regional models is now underway in ARCMIP (Arctic Regional Model Intercomparision Project), but the initial results are not expected until late in 2001.

There is a strong need to develop a regional coupled ocean-ice-atmosphere model to represent the entire Arctic. There are several groups who would like to work on an Arctic regional model, but none are securely funded to do so. ACIA could help fill this important gap.

Statistical Downscaling

Statistical downscaling techniques have been developed to reduce predictions of climate change from a global or regional model's grid scale to a much smaller spatial scale. Statistical downscaling techniques rely on available observations at a location as well as an understanding of the local terrain. At a very basic level, at least ten years of observational data are needed at a key location. From this core location, statistical downscaling for a surrounding region can be achieved if additional measurements are collected at a number of outlying locations. These outlying measurements can be

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collected over a one or two year period. This technique may be most useful for studies of terrestrial and infrastructure effects.

There has been considerable interest in applying statistical downscaling to a few locations within the time frame of this assessment. Statistical downscaling is naturally suited to areas with long-term climate records. Several locations, such as Toolik Lake, Abisko, the Russia Arctic, Alaska, and Svalbard, would be ideal for the application of such techniques because of their long-term meteorological and ecological monitoring. By applying downscaling techniques and producing estimates of future climate on a smaller, for instance 50m by 50m, scale, ecologists will be able to make better estimates of future environmental changes. Such an experiment would result in unprecedented predictions of the localized effects due to climate change. Several regional-scale projects are currently underway and it is proposed that this work could be completed within the ACIA time frame. There is a need to coordinate these efforts for their optimal utilization by ACIA.

Understanding Uncertainties

It is well recognized that the uncertainties associated with climate change predictions are large. These uncertainties are perhaps larger in the Arctic than in any other location in the world. The level of uncertainty makes it critical to address the issue of climate change scientifically and to make our best estimates of change in the Arctic jointly with our best estimates of the associated uncertainties. There are many uncertainties in the current model scenarios, including predictions of population growth, land use and emissions for the twenty-first century. Natural variability of the global climate system will limit the ability of models to precisely determine future climate change. This fundamental aspect of climate is particularly important in the Arctic because of the high natural variability and active feedback mechanisms.

Statistical significance of a change signal depends, in part, on the time interval over which the signal is analyzed. Particularly in the Arctic, decadal variability can be large and causes are not well understood. Large variability on all time scales requires that long time intervals be used to assess changes as projected from modeling efforts. There are additional uncertainties associated with global climate models, including those caused by a finite grid scale and limitations of our current understanding of climate. When predictions are carried through to regional models or are statistically downscaled, the errors may be either diminished or increased, depending on the parameters and the location. The scenarios working group will address these uncertainties using a number of currently available methods.

Parameters for Impacts Use

Several members of the impacts community were present to represent the needs of the terrestrial, marine and infrastructure communities in terms of climate predictions. It was recognized that the parameters and time and spatial scales needed to assess climate impacts differ significantly depending on the impact to be assessed. Marine studies are likely to require a small number of climate parameters, mainly sea ice coverage, ocean temperature, salinity, and critical inflow/outflow rates, while the terrestrial and infrastructure studies are likely to require several dozen parameters.

The impacts communities will need predictions of mean values as well as of extreme events. Current models are able to provide some of this information, although archival of the appropriate model output is a significant concern. In some cases, specific output parameters may need to be requested directly from the modeling agencies. Past data, appropriately adjusted by model predictions, can be used to provide additional knowledge of extreme events. It is not yet clear how well the models will be able to supply this information about extreme events and their combination.

The temporal nature of climatological events is significant in terms of many biological and other impacts. For example, seasonal trends are likely to be more significant than annual trends when examining impacts on many aquatic or terrestrial species. Autocorrelation of the events is also likely to be important. As an example, three warm winters in a row can be considerably more damaging to structures built on discontinuous permafrost than three warm winters interspersed with cold winters.

The table in Appendix 1 was adjusted from the CLIMPACT Table and summarizes the parameters suggested for ACIA impact studies. The information needs to be carefully examined by the authors of the other ACIA chapters both to determine if this list is inclusive of their needs and to prioritize the parameters and their associated time and spatial scales.

Many of the parameters listed in the table can be derived from the model output. For instance, if daily minimum and maximum temperatures are supplied, the number of days below critical temperature levels can be easily derived. However, in its existing form, the table represents more data than can reasonably be assimilated by any one group. There is an immediate need for the impacts groups to prioritize the parameters, time and spatial scales, and to identify which are most critical for completing the assessment. These few parameters can then be requested from a number of modeling centers and their uncertainties evaluated.

Terrestrial needs
In general, the list of parameters needed for the terrestrial impacts studies is considerably longer and the needs are more complex than those of marine impact communities. Specific parameters have been identified by terrestrial ecologists to be critical for an individual species' survival, such as –34 degrees for caterpillars. For other terrestrial effects, the rate of change is critical. Furthermore, the spatial resolution needs of terrestrial ecologists can be quite demanding. Terrain and ecosystems can vary

on scales of tens of meters. The terrestrial ecology community has requested that for a few intensively studied locations, such as Abisko and Toolik Lake, key parameters be provided at these higher resolution spatial scales.

Infrastructure needs
Two key issues are important for assessing infrastructure impacts. These are a full description of predicted permafrost changes and estimates of the likelihood of extreme events. The parameters of interest include the likelihood of several warm winters in a row and likelihood of flooding. It has been noted that multiple model runs will be needed to assess the likelihood of extreme events and that past data combined with model predictions can be useful for assigning probabilities. Key probabilities often related to the likelihood of events over time scales of 100 to 10,000 years. The spatial scale for infrastructure impacts is similar to that of terrestrial impacts: for small, select areas, predictions at a resolution of tens of meters would be most useful.

Marine needs
The ACIA Drafting Group on Marine Systems met in Copenhagen in January 2001 and discussed possible climate impacts and modeling needs. They also came up with a list of requests for the scenario group and concluded that modelers will unlikely be able to provide the marine drafting group with all parameters and variables wanted. The key issues for the marine impacts group can be divided into three groups: oceanic, sea ice and atmospheric. The oceanic parameters of interest are temperature and salinity, along with inflow and outflow estimates. For sea ice, monthly grids of ice concentration, thickness and velocity are requested. For atmospheric parameters, the requested parameters include daily grids of maximum and minimum temperature, precipitation and wind, along with cloud liquid water content and both UV and Photosynthetically Active Radiation (PAR).

Linkages to Impacts Communities

There is an immediate need to make model output data usable by environmental scientists. It was emphasized that non-atmospheric scientists may require assistance to be able to easily interpret output data from AOGCM model simulations.

It was pointed out that some facilities, such as the Canadian Center for Climate, the Hadley Center and the Max Planck Institute in Hamburg, currently have personnel devoted to assisting users with their model output. Other centers are moving in that direction, but the assistance offered can not be expected to fulfill all the needs of ACIA. It was emphasized that a dedicated effort will be required within ACIA to supply impacts researchers with model-generated scenarios in a suitable form. Both help in finding proper model output and help in designing meteorologically/oceanographically sensible impact studies will be needed. A starting point is the data currently available from the IPCC Data Distribution Centre (DDC). More detailed model output, including daily values and oceanographic data, can be obtained from individual modeling centers. A list of available resources needs to be constructed to begin helping the climate

impacts communities. However, the current situation is such that the authors of the impacts chapters will need to interact with an ACIA data distribution center to best utilize the large quantity of model output currently available.

Users of climate data require assistance to accurately understand the model uncertainties. As an example, how will daily minimum temperatures shift and what are the associated uncertainties for that prediction? Will the uncertainty be calculated from different scenarios? different models? different runs of the same scenario for the same model? Workshops, as well as dedicated personnel, will likely be needed to fully address this problem for the assessment.

Finally, despite the complexity of the current situation, the impacts groups are requesting best estimates of future climate change as soon as possible to begin their work. A first estimate of future climate change scenarios for a small set of key parameters needs to be produced as quickly as possible. For example, monthly averages of standard surface parameters such as temperature and precipitation are directly available from the IPCC DDC. These parameters can be used to calculate a first estimate of permafrost conditions in a future climate. To obtain more detailed information, such as daily minimum and maximum temperatures as well as other extreme variables, further data evaluation is needed. Where available, such key parameters can be estimated through regional models and/or statistical downscaling techniques to provide the impacts groups with the spatial resolution they are requesting. Finding out the final requirements for each impact study is likely to be an interactive process. Unless a facility for supplying impact studies with the appropriate climate scenario data is established, the ACIA process is likely to fail.

Appendix 1: Preliminary Estimates of Data Requirements for ACIA

Table 1: *Some specific parameters needed to assess climate change impacts. The table outlines three categories of impacts to the Arctic at specified spatial and temporal scales.*

Sector / Parameter		Marine		Terrestrial		Infrastructure & Human health	
		x	t	x	T	X	t
Air Temperature	Mean monthly	100s km	Monthly	50m	season.	10s km	monthly
	Max / Min T	100s km	Season.	50m	Daily	10s km	monthly
	Frequ. T_{thresh}			50m	season.		
	GDD (≥0°C)			50m	Season		
	GDD (≥5°C)			50m	season.		
	HDD (≤18°C)			50m	season.		
Soils — water balance	Moisture			50m	monthly		
	Evapotranspir.			50m	monthly		
	water table hght			50m	monthly		
	Flooding			50m	monthly		monthly
Permafrost	active layer depth			50m	monthly		monthly
	active layer detac			50m	monthly		monthly
	Subsidence			50m	monthly		monthly
	extent perm.			50m	monthly		monthly
	extent disc. perm			50m	monthly		monthly
Hydrology	Air Relative humidity						monthly
Clouds	presence	grid	monthly	50m	monthly		monthly
	liquid water	grid	monthly				
Precipitation	Mean monthly	grid	monthly	50m	season.	10s km	monthly
	Freezing rain						monthly
	P_{max} 24h					10s km	monthly
	D, FWI, H					10s km	monthly
Snow	Extent					10s km	monthly
	Ice layers			50m	monthly		
	frozen ground			50m	seasonal		
	Thickn. distr.					10s km	monthly
	Timing					10s km	monthly
Runoff	Magnitude	monthly	monthly				
	Timing						

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Wind	Mean monthly W	10s km	monthly	50m	monthly		monthly
	Extreme events			50m	monthly	10s	monthly
Radiation	UV	grid	monthly	grid	daily		seasonal
	PAR	grid	monthly	grid	daily		
Ocean	Temperature	vert. resolved	Monthly				
	Salinity	vert. resolved	Monthly				
	Sea level						seasonal
	Wave Height						seasonal
	Inflow/outflow	vert. resolved	Monthly				
O₃	Total column	grid	Monthly	grid	weekly		seasonal
	Tropospheric			100s km	weekly		seasonal
	Extreme events		Monthly	10s km	monthly		seasonal
Sea ice	Spatial extent	grid	Monthly				
	Thickn. distr.	grid	Monthly				
	Velocity	grid	Monthly				

Explanations

The above table provides an overview of the data/information required to assess the impacts of climate change for three categories of impacts in the Arctic. The information needed relates primarily to climatic parameters including basic sea ice properties. The two categories **x** and **t** indicate at which spatial and temporal scales the required parameters should be made available. The data/information needs represented here are best estimates based on this meeting. The table does not attempt to provide an exhaustive or a completely correct overview.

The parameters listed in the tables above are described in more detail below:

Symbols in Table 1	**Explanation**
Mean monthly T	Mean monthly temperature (based on six-hourly to daily values)
Max / Min T	Maximum and minimum daily values
Frequ. T_{thresh}	Frequency of exceeding threshold temperatures within the specified time frame
GDD (≥0°C)	Growing degree days (≥0°C) within the specified time frame
GDD (≥5°C)	Growing degree days (≥5°C) within the specified time frame
HDD (≤18°C)	Heating degree days (≤18°C) within the specified time frame
Moisture	Soil Moisture
Evapotranspiration	Monthly estimates of terrestrial evapotranspiration
Water table height	Average height of water table over land
Flooding	Occurrence and severity of flooding
Active layer depth	Depth of active layer
Active layer detac	Detachment of active layer
Subsidence	Estimates of subsidence depth

Extent perm	Geographic extent of permanent permafrost
Extent disc perm	Geographic extent of discontinuous permafrost
Air relative humidity	Relative humidity at 2 meters
Clouds - presence	Indicators of cloud occurrence and optical depth
Clouds – liquid water	Liquid water content of clouds (related to optical depth)
Precipitation – Mean monthly	Monthly means of both frozen and liquid precipitation
Freezing rain	Occurrence of freezing rain
P_{max} 24h	Maximum precipitation during 24h
D, FWI, H	Droughts, fire weather index, humidity
Snow - Extent	Spatial extent of snow cover
Snow – Ice layers	Existence of ice layers within snow
Snow – Frozen Ground	Indicator of whether snow occurs over frozen or thawed ground
Snow - Thickn. Distr.	Snow thickness distribution
Snow - Timing	Timing of development and disappearance of snow cover (days)
Runoff - Magnitude	Magnitude of runoff at watersheds
Runoff - Timing	Timing of runoff at particular watersheds (days to weeks)
Wind - Mean monthly W	Mean monthly wind velocity (based on six-hourly to daily values)
Wind - Extreme events	Extreme events with regard to storminess
Radiation - UV	Biologically effective ultraviolet radiation on horizontal and vertical surfaces
Radiation - PAR	Photosynthetically Active Radiation
Ocean - temperature	Temperature profiles
Ocean - salinity	Salinity profiles
Ocean – sea level	Sea level in meters above reference
Ocean – wave height	Geometric mean of wave heights
Inflow - outflow	Inflow and outflow from all sources, including river runoff and precip
Ozone – total column	Total ozone in Dobson Units
Ozone - tropospheric	Ozone concentration at 2 meters
Ozone – extreme events	Severe depletion episodes
Spatial extent	Spatial extent of sea ice cover
Thickn. Distr.	Thickness distribution of sea ice cover
Velocity	Speed of ice movements
100s km	Spatial scale : 100s of kilometers
10s km	Spatial scale : 10s of kilometers
Kms	Spatial scale : several kilometers
Monthly	Temporal scale : monthly
season.	Temporal scale : seasonal

Appendix 2: List of Acronyms

IPCC	Intergovernmental Panel on Climate Change
WMO	World Meteorological Organization
CAFF	Conservation of Arctic Flora and Fauna
CMIP	Coupled Modeling Intercomparison Project
AOGCM	Atmosphere-Ocean General Circulation Model
CLIMPACT	Regional Climate Modelling and Integrated Global Change Impact Studies in the European Arctic.
ACIA	Arctic Climate Impact Assessment
UV	Ultraviolet Radiation
AMAP	Arctic Monitoring Assessment Program
IASC	International Arctic Science Committee
SRES	IPCC Special Report on Emission Scenarios
DDC	IPCC Data Distribution Centre
RCM	Regional Climate Model

Appendix 3: Workshop agenda

Monday 29 January

08.30	Registration	
09.00	Welcome	Erland Källén/Eva Kettis
09.10	Introduction to ACIA	Bert Bolin/Bob Corell

Global climate model performance in the Arctic region
Chairperson: Erland Källén

09.30	Hadley Centre model simulation of Arctic climate and climate change	Howard Cattle
09.50	Climate change of the Arctic Region as forced by global anthropogenic effects	Lennart Bengtsson
10.10	Models, simulations and studies of Arctic climate and change at the Canadian Centre for Climate Modelling and Analyses (CCCma)	John Fyfe
10.30	Coffee	
11.00	GFDL Global Climate Model Simulations: Focus on the Arctic	Keith Dixon
11.20	Intercomparison Study of Arctic Oscillation (AO) and AO-like Climate Change Simulated by the MRI and Other Coupled General Circulation Models	Akira Noda
11.40	Climate change simulations with the NCAR, CCSM and PCM	John Weatherly
12.00	Global model intercomparison	Vladimir Kattsov
12.20	Lunch	

Regional climate modeling at high latitudes
Chairperson: Vladimir Kattsov

13.30	High latitude, high resolution atmospheric modeling – adding value?	Jens Hesselbjerg-Christensen
13.50	RegClim, Norway simulations	Trond Iversen
14.10	Coupled ocean-ice-atmospheric regional climate modeling	Markku Rummukainen

14.30 The Arctic Regional Climate System Model   John Walsh (Amanda
Lynch)
        (ARCSyM)

14.50 Coffee

15.10 Empirical downscaling – some examples from   Inger Hanssen-Bauer
        Norway and Svalbard

Ozone and UV radiation
Chairperson: Elizabeth Weatherhead

15.30 The impact of greenhouse gases and halogenated   Petteri Taalas
        species on future solar UV radiation doses

15.50 Ozone and UV flux data and modelling for the Arctic   Igor Karol

16.10 Close

Tuesday 30 January

Impact studies
Chairperson: John Walsh

09.00 Climate Impact Studies in the Arctic   Manfred Lange

09.20 Possible impacts on marine ecosystems   Harald Loeng

09.40 Impact on Arctic infrastructures   Arne Instanes

10.00 UV impact studies   Elizabeth Weatherhead

10.20 Coffee

10.50 Break-up into discussion groups

The discussion groups should address both (1) what is needed from an impact study
point of view and (2) what is realistically available from present-day models, as well as
optimal strategies for meshing (1) and (2).

Group structure:
        Marine Breakout Group
        Chairman: Lennart Bengtsson; Rapporteur: John Walsh

        Terrestrial Breakout Group
        Chairman: Howard Cattle; Rapporteur: Elizabeth Weatherhead

        Infrastructure Breakout Group
        Chairman: Erland Källén; Rapporteur: Jouni Räisänen

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